

UNITED STATES AIR FORCE RESEARCH LABORATORY

CROWD CONTROL CEP BLUNT IMPACT INDUCED EFFECTIVENESS ASSESSMENT

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14. ABSTRACT The purpose of this report is to compare and contrast selected Crowd Control Concept Exploration Program technology candidates with regards to their ability to produce an intended effect at target. This report will approach this objective from an induction of pain perspective, and all payloads will be blunt impact munitions. This report does not address injury producing potential of any of the technology candidates. However, the ability to cause injury should be considered just as important, if not more, than induction of an effective behavioral response.					
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EXECUTIVE SUMMARY

1 OBJECTIVE

The purpose of this report is to compare and contrast selected Crowd Control Concept Exploration Program technology candidates with regards to their ability to produce an intended effect at target. This report will approach this objective from an induction of pain perspective, and all payloads will be blunt impact munitions. This report does not address injury producing potential of any of the technology candidates. However, the ability to cause injury should be considered just as important, if not more, than induction of an effective behavioral response.

2 ASSUMPTIONS

- 2.1 Induction of pain is determined from impact of only one pellet, multiple pellet impacts are not considered
- 2.2 Pain induction calculations do not take into account probability of hit
- 2.3 The risk assessment is based on a "per shot risk". The case of multiple shooters is not considered.
- 2.4 Pain thresholds are the same no matter what part of body is impacted
- 2.5 Startle effects were not considered
- 2.6 All kinetic energy carried by projectile is delivered to target (no compliance)
- 2.7 The MK19 LR and 12 gauge fire a canister down range that detonates five feet from target

3 SYSTEM INFORMATION

Only three candidate technologies are addressed in this report. After all of the available data was collected for the seven Crowd Control CEP technology candidates, only the MK19 SR, MK19 LR, and 12 gauge shotgun were mature enough to warrant this level of assessment. The other Crowd Control technologies, or their desired payload, are still conceptual at this point, and are not discussed in this report.

4 SYSTEM EFFECTIVENESS

All three candidates, the MK19 SR, MK19 LR, and the 12-gauge shotgun, have the potential to induce an intense stinging effect on target. However, while the MK19 LR and 12-gauge shotgun (with velocities > 97 m/s) have the potential to induce an intense stinging effect on target at the desired operational ranges, this analysis indicates that the MK19 SR will only induce an intense pain effect at ranges under 55 meters, and a mild pain effect at ranges under 80 meters. The technology candidates that are most effective from an induction of pain

perspective are the MK19 LR at ranges >25 meters and the MK19 SR at ranges <25 meters.

1.0 Introduction

The purpose of this report is to compare and contrast selected Crowd Control Concept Exploration Program technology candidates with regards to their ability to produce an intended effect at target. This report will approach this objective from an induction of pain perspective, and all payloads will be blunt impact munitions. This report does not address injury producing potential of any of the technology candidates. However, the ability to cause injury should be considered just as important, if not more, than induction of an effective behavioral response.

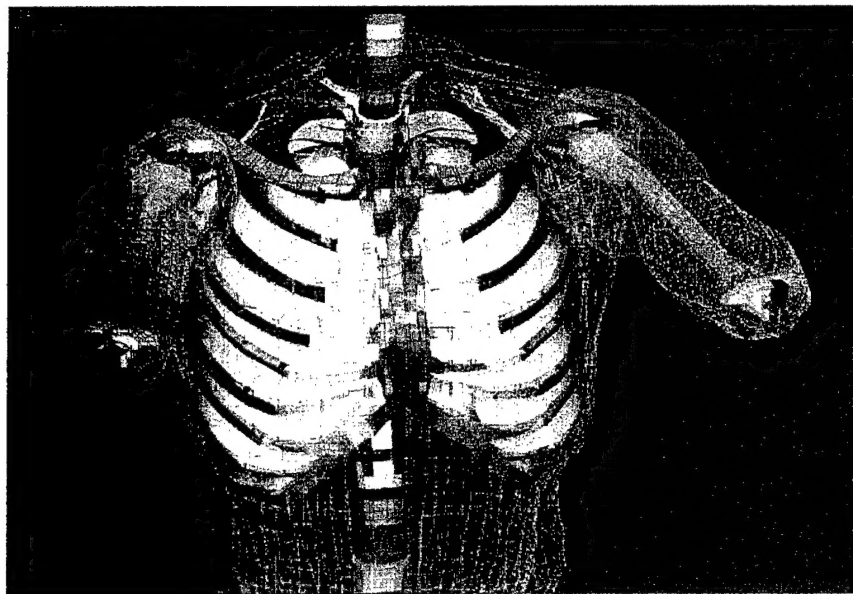
The approach involved collecting data (impact velocity, intended range, caliber, projectile mass, etc.) for each of the seven Crowd Control CEP technology candidates (Table 1) and then using that data to calculate the energy density (KE/A) of the projectile at impact. Once the energy density is known, it can be compared to some pain metric. It should be stated here that using energy density to represent an impact condition is not an attempt to mimic the biomechanical processes that occur with blunt impact. A biomechanical approach would potentially involve the use of finite element models (Figure 1) to simulate the body as it undergoes tissue and organ strain caused by the impacting stressor. From a pain perspective, energy density will not give a representation of the processes involved with stimulation of nociceptors. Unfortunately, these biomechanical approaches are not yet available for non-lethal weapon application. Another factor that isn't considered in this analysis is compliance of the projectiles. A compliant projectile will absorb some of the energy upon impact as it deforms, resulting in less energy being delivered to the target. The assumption we used is that all of the energy carried by the projectile is delivered to the target, perhaps overestimating the energy density at target upon impact. Knowing this, the approach used was to compare energy density to a pain metric, either anecdotal or from the literature, so that a quantitative comparison could be made between the technology candidates from an induction of pain perspective to aid in the down-select process.

Table 1. The Seven Crowd Control Technology Candidates

1. Active Denial System (ADS)
2. 40mm MK19 w/ CDC (short range)
3. 40mm MK19 long range
4. Unmanned ground vehicle
5. Unmanned ground vehicle w/ tube-launched munitions
6. Enhanced M203
7. 12 gauge shotgun w/ launch cup

As several of the Crowd Control CEP technology candidates, and/or their payloads, are only conceptual at this point, it became clear during the data gathering process that those systems could not be assessed for a blunt impact induced effectiveness. Actual data for three of the seven candidates could be obtained and thus this report only reports on the two MK19's and the 12-gauge shotgun. However, as data becomes available for the other candidates the same type of analysis should be done.

Figure 1. Finite Element Model of the Thorax



2.0 Pain Metric

The principle mechanism by which a blunt impact non-lethal weapon is expected to achieve its desired effect is thru induction of pain. If the effects of startle are not considered, and they are not in this report, then pain is the only mechanism that has the potential to affect behavior. Variables such as motivation, gender, age, etc., will have some effect on how much pain an individual will endure before their behavior is altered. However, these variables were not considered in this analysis as valid data is not yet available to determine their impact.

In the past, effectiveness caused by blunt impact has been assessed using terms such as deny, delay, distract, deter, etc. These measures of effectiveness are qualitative in nature, and unfortunately are very hard to

measure quantitatively due to variables such as motivation. Our methodology was to review the literature to find a relationship between a projectile impact parameter (i.e. velocity) and sensation of pain. This would allow us to do a quantitative assessment of the technology candidates, which can be directly used as a down-select tool for Crowd Control.

There is relatively little data available in the refereed scientific literature on mechanically-evoked cutaneous pain.^{1,2} Most of this work has been done in the skin of the hand and it is unclear how this will generalize to other parts of the body. There is no data in the refereed literature dealing with the effects of mechanically evoked cutaneous pain on ongoing behavior. An unpublished study by Sherry (2002) demonstrated that a single 32-caliber projectile fired at 625 ft/sec did not stop a motivated, highly trained swine from pressing a panel for a food reward. Chief Petty Officer Kurt Pratterra (personal communication) reported that during training of Navy security personnel at the Naval Fleet Training Center (NFTC), the recruits were shot with 68 caliber, 3.17g RP Scherer or PMI paint balls fired from a Tippman pro-carbine, pro-68, or pro-lite paint ball gun. These guns were calibrated everyday to deliver muzzle velocities of 185 ft/sec (2.15 J/cm²) and 240 ft/sec (3.62 J/cm²). At 240 ft/sec personnel wearing a t-shirt and standing at a distance of 5 ft (1.52 m) experienced significant pain and their behavior was disrupted no matter what activity they were performing. The projectile broke the skin, drew blood, and often left a residual scar. At 185 ft/sec, the lower bound for pain according to Mr. Pratterra, some individuals experienced pain while others did not. Muzzle velocities are not expected to decay much over a range of 5 ft. so these velocities can also be thought of as impact velocities.

The NFTC exposures seem most relevant to the current effort for a variety of reasons. Most importantly, it is the only exposure data of human targets performing a behavior. The exposures also occurred with military personnel, perhaps similar in body type to a potential target, and finally, the disruption of behavior was well detailed. Therefore, for this report, we will assume that a painful sensation or a mild stinging effect is first noted at 2.15 J/cm². An intense stinging, causing disruption of behavior every time, is first noted at 3.63 J/cm². Granted, these thresholds are anecdotal in nature, and should be taken as such. However, until more appropriate data or models become available, this is the best data available. Again, exceeding these energy densities only implies that some level of pain is achievable and with that level of pain there is a likelihood of influencing a target's behavior, not knowing the motivation level of that target. If the technology is to be demonstrated to be effective against a motivated target, behavioral (either animal or human) testing must be accomplished.

¹ Greenspan, J. D., LaMotte, R. H. "Cutaneous mechanoreceptors of the hand: Experimental studies and their implications for clinical testing of tactile sensation." *J. Hand Ther.* 6, pp. 75-82, 1993.

² Koltzenburg, M., Handwerker, H. O. "Differential ability of human cutaneous nociceptors to signal mechanical pain and to produce vasodilatation." *J. Neurosci.* 14, pp. 1756-65, 1994.

3.0 Data Analysis

Data collected for the three candidate systems is detailed in Table 2. The first step was to calculate the energy density at impact for each of the candidates. This was relatively easy for the MK19 long range and the 12-gauge shotgun. These two candidates launch a canister (i.e. grenade) out to the target. The canister then detonates ejecting the projectiles outward. Because the distance between the spot where the canister detonates and the target is very small, the effects of air drag on the projectiles were neglected, meaning the velocity at ejection is equivalent to the velocity of the projectile at impact.

For the MK19 short range, the projectiles are fired out of the muzzle directly. The distance between the muzzle and intended target is far enough that effects of air drag must be considered. The air drag was calculated for the projectile fired from the MK19 short range and the velocity at every five meters from 5 meters to 150 meters was calculated. Depending on where the target is, the velocity at that range can be used to calculate the energy density upon impact. The velocity decay due to drag for the MK19 SR can be seen in Table 3. A graphical depiction of the velocity decay can be seen in Figure 2.

Table 2. Technology Information

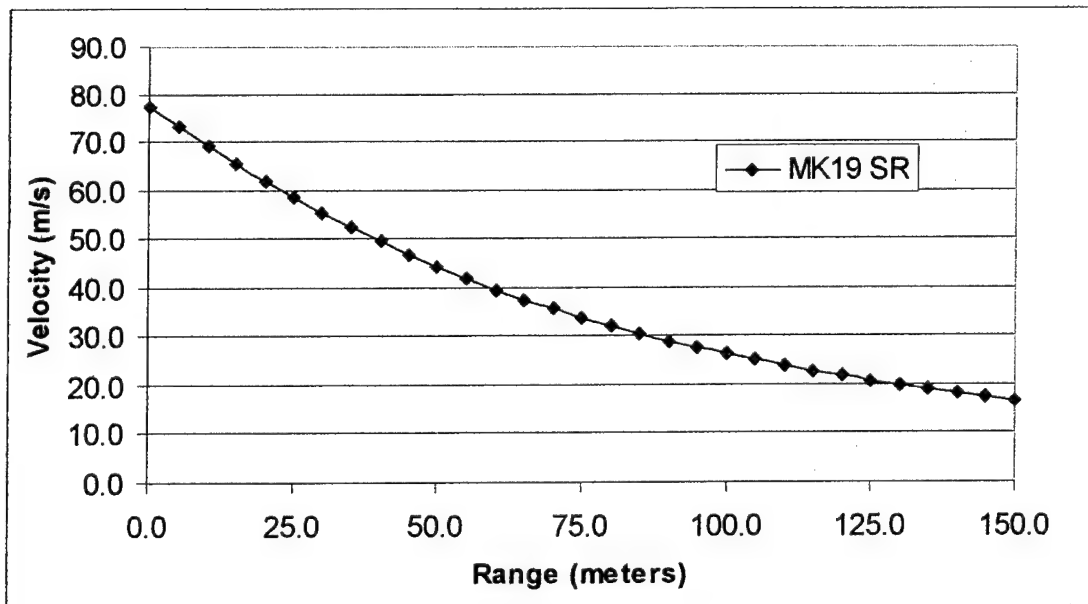
Technology	Round	Projectile Caliber	Projectile Mass (g)	MV (m/s) Canister	MV (m/s) Projectile	Range (m)
MK19 SR	XM1044	40 cal	3.25	----	77.4	10-150
MK19 LR	XM1043	32-48 cal	0.4-1.30	241.1	106.7	50-1500
12 Gauge	NLBHG	32 cal	0.4	186.0	30.5-106.7	60-100

MV = Muzzle Velocity

Table 3. MK19 SR Velocity Decay

Range (m)	Velocity (m/s)	Range (m)	Velocity (m/s)
5.20	73.2	80.0	32.1
10.1	69.1	85.0	30.5
15.2	65.5	90.0	29.0
20.2	61.9	95.0	27.6
25.2	58.6	100.0	26.3
30.2	55.4	105.0	25.1
35.1	52.4	110.0	23.9
40.0	49.5	115.0	22.8
45.1	46.8	120.0	21.8
50.1	44.3	125.0	20.8
55.0	42.0	130.0	19.9
60.1	39.7	135.0	19.1
65.1	37.6	140.0	18.2
70.0	35.7	145.0	17.5
75.0	33.9	150.0	16.8

Figure 2. Velocity Decay for MK19 Short Range



Energy density is simply the kinetic energy of the projectile divided by the effective cross-sectional area of the projectile. An example calculation for the MK19 SR at 10 meters is shown below. This process was used to calculate the energy densities for all three candidates, including the MK19 SR at the various ranges.

R = Radius of Projectile (cm)

A = Cross-sectional Area of Projectile = πR^2 (cm²)

M = Mass of Projectile (kg)

V = Velocity of Projectile (m/s)

KE = Kinetic Energy = $.5MV^2$

J = Joules ((kg*m²)/sec²)

At 10.3 meters KE/A = $(.5MV^2)/(\pi R^2)$

= $[(.5)(.00325)(69.1)^2] / [(\pi)(.508)^2]$

= 7.76 / .811

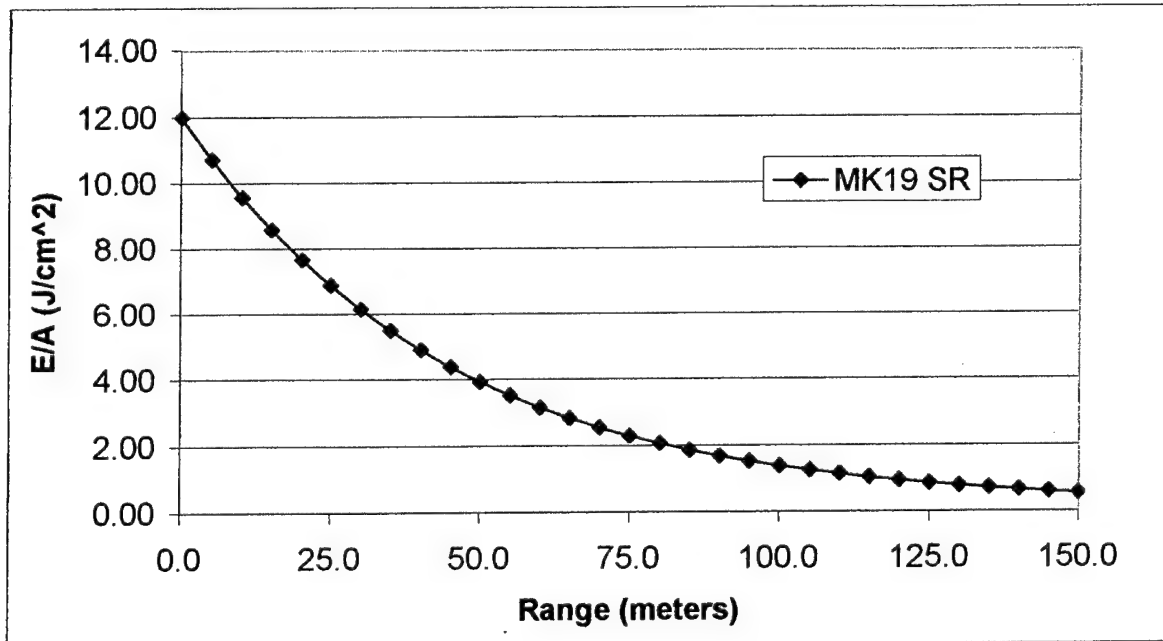
= 9.57 J/cm²

The energy density for the 12-gauge shotgun, which utilizes 32 caliber projectiles at an impact velocity of 30.5 m/s is 0.36 J/cm². At 61 m/s, the energy density at impact is 1.43 J/cm², and at 106.7 m/s the energy density at impact is 4.33 J/cm². For the MK19 LR, the energy density was calculated using an impact velocity of 106.7 m/s for both 32 and 48 caliber projectiles, as the caliber of choice for the MK19 LR has not yet been determined. For the 32-caliber option, the MK19 LR delivers an energy density of 4.33 J/cm² upon impact and for the 48-caliber option the MK19 LR delivers an energy density of 6.34 J/cm² upon impact. The energy densities delivered by the MK19 SR at various ranges can be seen in Table 4. A graphical depiction of the energy density delivered at various ranges for the MK19 SR can be seen in Figure 3.

Table 4. Energy Densities Delivered by MK19 SR Upon Impact

Range (m)	E/A (J/cm ²)	Range (m)	E/A (J/cm ²)
5.20	10.73	80.0	2.07
10.1	9.58	85.0	1.87
15.2	8.60	90.0	1.69
20.2	7.67	95.0	1.53
25.2	6.88	100.0	1.39
30.2	6.15	105.0	1.26
35.1	5.50	110.0	1.15
40.0	4.91	115.0	1.04
45.1	4.39	120.0	0.95
50.1	3.94	125.0	0.87
55.0	3.53	130.0	0.79
60.1	3.16	135.0	0.73
65.1	2.84	140.0	0.67
70.0	2.55	145.0	0.61
75.0	2.30	150.0	0.56

Figure 3. MK19 SR Delivered Energy Density Decay

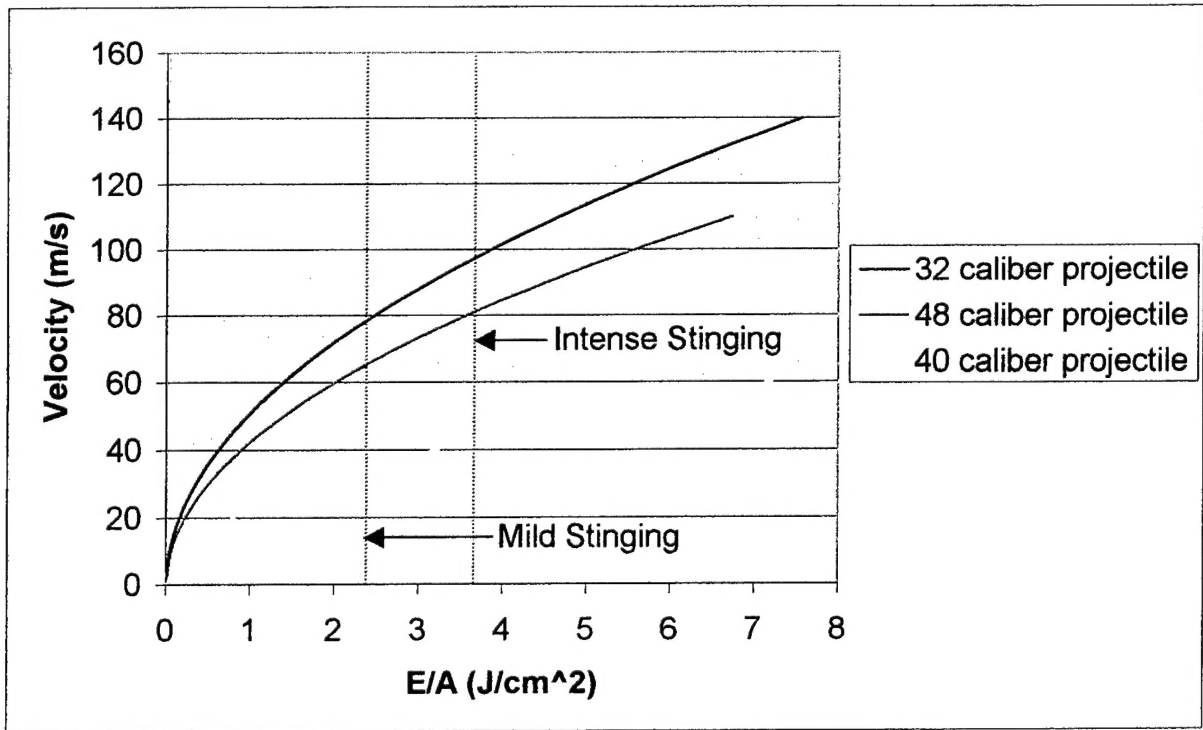


4.0 Results and Discussion

The energy densities as a function of velocity are shown for 32, 40 and 48 caliber projectiles in Figure 3. It is apparent that the 40 caliber projectile used with the MK19 SR would achieve energy densities associated with pain at a lower velocity than the 32 and 48 caliber projectiles used with the MK19 LR and 12 gauge. The 32 caliber projectile would need to have an impact velocity of 74.7 m/s to cause a mild pain (2.15 J/cm^2) and an impact velocity of 96.9 m/s to induce an intense stinging (3.63 J/cm^2). The 48 caliber projectile would need to have an impact velocity of 62.1 m/s to cause mild pain (2.15 J/cm^2) and an impact velocity of 80.6 m/s to cause an intense stinging (3.63 J/cm^2). The 40 caliber projectile would need to have an impact velocity of 32.8 m/s to cause mild pain (2.15 J/cm^2) and an impact velocity of 42.5 m/s to cause an intense stinging (3.63 J/cm^2).

The MK19 LR with 32 caliber projectiles would deliver an energy density of approximately 4.33 J/cm^2 to the target with an impact velocity of 106.7 m/s. Using the 48 caliber projectiles the MK19 LR would deliver approximately 6.34 J/cm^2 to the target with the same impact velocity. The NFTC exposures, as discussed above, indicated a mild pain threshold of 2.15 J/cm^2 and an intense stinging effect capable of changing behavior at approximately 3.62 J/cm^2 . It is clear that both potential calibers for the MK19 LR would allow the technology to deliver energy densities to the target, which exceed the intense stinging, behavior-changing threshold. The MK19 LR at impact with a 32 caliber projectile exceeds the intense stinging threshold by ~20% and the mild pain threshold by ~53%. The 48 caliber option for the MK19 LR at impact exceeds the intense stinging threshold by ~43% and the mild pain threshold by ~66%. These results, while based upon anecdotal pain thresholds, would seem to indicate that the MK19 LR will be effective at inducing a painful, behavior altering response at the target.

Figure 4. Velocities and E/A for 32 and 48 Cal Projectiles



The 12 gauge shotgun using 32 caliber projectiles would deliver energy densities of 0.36, 1.49, and 4.33 J/cm² with impact velocities of 30.5, 61, and 106.7 m/s respectively. This would indicate that the 12 gauge would only be effective at the highest impact velocity of 106.7 m/s at causing an intense stinging. At an impact velocity of 74.7 m/s, the 12 gauge would cause a mild pain (2.15 J/cm²), with an intense stinging effect beginning with a velocity of 96.9 m/s (3.63 J/cm²).

The MK19 SR, depending on the range to target, will deliver varying amounts of energy density to the target. It is obvious that as range to target increases, velocity of the projectile at impact decreases, resulting in a lower energy density being delivered at the longer ranges. From Table 4 we can see that the MK19 SR delivers an energy density to target greater than the intense stinging, behavioral altering threshold at ranges less than 55 meters. At some point between 75 and 80 meters, the MK19 SR projectiles cease to exceed the mild pain threshold in terms of energy density. From 80 meters on out to 150 meters, at no point does the energy delivered by the MK19 SR projectiles exceed either the mild or intense stinging threshold. Figure 5 displays this graphically. The energy density was plotted on a logarithmic scale. At the mild and intense pain thresholds, a line was extrapolated from the x-axis to the curve, outlining

ranges for which the MK19 SR will have the capability to produce both a mild and intense stinging. The region in yellow denotes the ranges at which the MK19 SR may induce a mild pain. The region in red denotes the ranges at which the MK19 SR may induce an intense pain, in which behavior will be altered.

The velocities for all candidates required to cause mild an intense pain as well as the actual velocities of these technologies at the desired ranges are shown in Table 5. The intended ranges can be found in Table 2. Table 5 indicates that the MK19 LR velocity at the intended ranges exceeds both the mild and intense pain threshold. The same is true for the 12-gauge at higher projectile velocities. The MK19 SR can exceed both the mild and intense stinging thresholds depending on the range.

Figure 5. MK19 SR Energy Density Decay

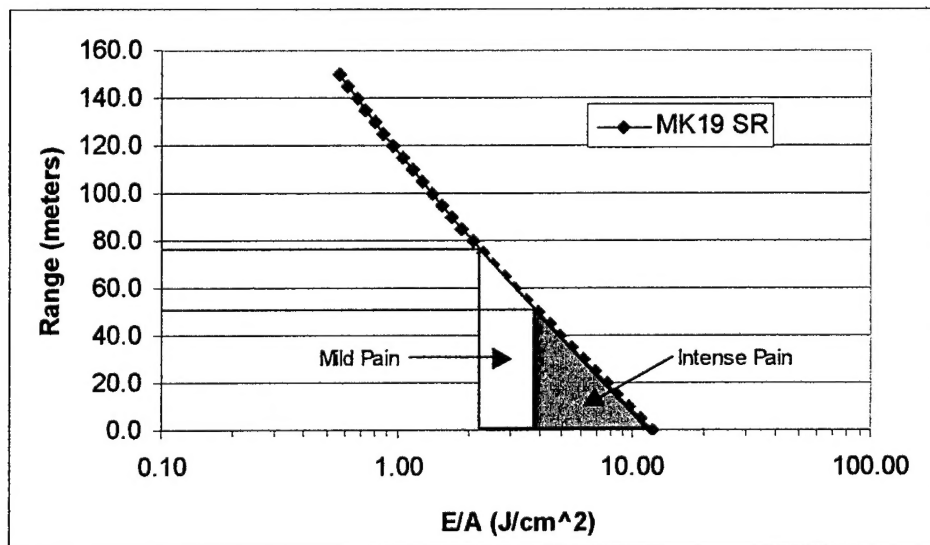


Table 5. Velocities Required to Induce Pain

	MK19 SR (40 cal)	MK19 LR (32 CAL)	MK19 LR (48 CAL)	12-Gauge (32 CAL)
Mild Pain Velocity (m/s)	32.8 (2.15)	74.7 (2.15)	62.1 (2.15)	74.7 (2.15)
Intense Pain Velocity (m/s)	42.5 (3.62)	96.9 (3.62)	80.6 (3.62)	96.9 (3.62)
Desired Range Velocity (m/s)	16.8-69.1 (0.56-9.58)	106.7 (4.33)	106.7 (6.34)	30.5-106.7 (0.36-4.33)

E/A in parentheses (J/cm²)

5.0 Conclusions

This report assessed three Crowd Control technology candidates for their potential of causing blunt trauma induced effectiveness. All three candidates, the MK19 SR, MK19 LR, and the 12-gauge shotgun, have the potential to induce an intense stinging effect at target. The MK19 LR and 12-gauge shotgun have the potential to induce an intense stinging effect to target at the desired ranges. This analysis indicates that the MK19 SR will only induce an intense pain effect at ranges less than 55 meters and a mild pain at ranges less than 80 meters. The technology candidates that are most effective from an induction of pain perspective would be the MK19 LR at ranges > 25 meters and the MK19 SR at ranges < 25 meters.

This assessment was based upon anecdotal pain thresholds, and thus the predictions of this report must be read with that in mind. When assessing blunt impact induced effectiveness from a physiological perspective, induction of pain must be the metric used. Unfortunately, there is a paucity of pain data available. Hopefully in the future, more data will become available, allowing for more robust assessments of blunt trauma induced effectiveness, from a pain perspective, on a target.